Chapter 7
Flood-Runoff Analysis

7-1. Introduction

Flood-runoff analysis is usually required for any reservoir project. Even without flood control as a purpose, a reservoir must be designed to safely pass flood flows. Rarely are there sufficient flow records at a reservoir site to meet all analysis requirements for the evaluation of a reservoir project. This chapter describes the methods used to analyze the flood hydrographs and the application of hypothetical floods in reservoir projects. Most of the details on methods are presented in EM 1110-2-1417. The dam safety standards are dependent on the type and location of the dam. ER 1110-8-2 defines the requirements for design floods to evaluate dam and spillway adequacy. Requirements for flood development and application are also provided.

7-2. Flood Hydrograph Analysis

a. Unit hydrograph method. The standard Corps procedure for computing flood hydrographs from catchments is the unit hydrograph method. The fundamental components are listed below:

(1) Analysis of rainfall and/or snowmelt to determine the time-distributed average precipitation input to each catchment area.

(2) Infiltration, or loss, analysis to determine the precipitation excess available for surface runoff.

(3) Unit hydrograph transforms to estimate the surface flow hydrograph at the catchment outflow location.

(4) Baseflow estimation to determine the subsurface contribution to the total runoff hydrograph.

(5) Hydrograph routing and combining to move catchment hydrographs through the basin and determine total runoff at desired locations.

For urban catchments, the kinematic-wave approach is often used to compute the surface flow hydrograph, instead of unit hydrograph transforms. Each of the standard flood runoff and routing procedures is described in Part 2 of EM 1110-2-1417. HEC-1 Flood *Hydrograph Package* (HEC 1990c) is a generalized computer program providing the standard methods for performing the required components for basin modeling.

b. Rainfall-runoff parameters. Whenever possible unit hydrographs and loss rate characteristics should be derived from the reconstitution of observed storm and flood events on the study watershed, or nearby watersheds with similar characteristics. The HEC-1 program has optimization routines to facilitate the determination of best-fit rainfall-runoff parameters for each event. When runoff records are not available at or near the location of interest, unit hydrograph and loss characteristics must be determined from regional studies of such characteristics observed at gauged locations. Runoff and loss coefficients can be related to drainage basin characteristics by multiple correlation analysis and mapping procedures, as described in Chapter 16, “Ungauged Basin Analysis” of EM 1110-2-1417.

c. Developing basin models. Flood hydrographs may be developed for a number of purposes. Basin models are developed to provide hydrographs for historical events at required locations where gauged data are not available. Even in large basins, there will be limited gauged data and many locations where data are desired. With some gauged data, a basin model can be developed and calibrated for observed flood events. Chapter 13 of EM 1110-2-1417 provides information on model development and calibration.

d. Estimating runoff. Basin models can estimate the runoff response under changing conditions. Even with historical flow records, many reservoir studies will require estimates of flood runoff under future, changed conditions. The future runoff with developments in the catchment and modifications in the channel system can be modeled with a basin runoff model.

e. Application. For reservoir studies, the most frequent application of flood hydrograph analysis is to develop hypothetical (or synthetic) floods. The three common applications are frequency-storms, SPF and PMF. Frequency-based design floods are used to develop flood-frequency information, like that required to compute expected annual flood damage. SPF and PMF are used as design standards to evaluate project performance under the more rare flood events.

7-3. Hypothetical Floods

a. General. Hypothetical floods are usually used in the planning and design of reservoir projects as a primary basis of design for some project features and to substantiate the estimates of extreme flood-peak frequency. Where runoff data are not available for computing frequency curves of peak discharge, hypothetical floods can be used to establish flood magnitudes for a specified frequency from rainstorm events of that frequency. This approach is not accurate where variations in soil-moisture conditions and rainfall distribution characteristics greatly influence flood magnitudes. In general, measured data should be used to the maximum extent possible, and when approximate methods are used, several approaches should be taken to compute flood magnitudes.

b. Frequency-based design floods. In areas where infiltration losses are small, it may be feasible to compute hypothetical floods from rainfall amounts of a specified frequency and to assign that frequency to the flood event. NOAA publishes generalized rainfall criteria for the United States. They contain maps with isopluvial lines of point precipitation for various frequencies and durations. These point values are then adjusted for application to areas greater that 10 square miles, based on precipitation duration and catchment area. Section 13-4 of EM 1110-2-1417 provides information on simulation with frequency-based design storms.

c. Standard project flood. The SPF is the flood that can be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the region in which the study basin is located. The SPF, which provides a performance standard for potential major floods, is based on the Standard Project Storm (SPS).

(1) The SPS is usually an envelope of all or almost all of the storms that have occurred in a given region. The size of this storm is derived by drawing isohyetal maps of the largest historical storms and developing a depth-area curve for the area of maximum precipitation for each storm. Depth-area curves for storm rainfall of specified durations are derived from this storm-total curve by a study of the average time distribution of precipitation at stations representing various area sizes at the storm center. When such depth-area curves are obtained for all large storms in the region, the maximum values for each area size and duration are used to form a single set of depth-area-duration curves representing standard project storm hyetographs for selected area sizes, using a typical time distribution observed in major storms. EM 1110-2-1411 provides generalized SPS estimates for small and large drainage basins, and projects for which SPF estimates are required. The generalized rainfall criteria and recommended procedures for SPS computations for U.S. drainage basins located east of the 105^{th} longitude are presented.

(2) The SPF is ordinarily computed using the unit hydrograph approach with the SPS precipitation. The unit hydrograph and basin losses should be based on reasonable values for a flood of this magnitude. Part 2 of EM 1110-2-1417 provides detailed information on the unit hydrograph procedure and the simulation of hypothetical floods is described in Chapter 13. The computer program HEC-1 *Flood Hydrograph Package* provides the SPS and SPF computation procedures, as described in the SPF determination manual.

(3) While the frequency of the standard project flood cannot be specified, it can be used as a guide in extrapolating frequency curves because it is considered to lie within a reasonable range of rare recurrence intervals, such as between once in 200 years and once in 1,000 years.

d. Probable maximum flood. The PMF is the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The PMF is calculated from the Probable Maximum Precipitation (PMP). The PMP values encompass the maximized intensity-duration values obtained from storms of a single type. Storm type and variations of precipitation are considered with respect to location, areal coverage of a watershed, and storm duration. The probable maximum storm amounts are determined in much the same way as are SPS amounts, except that precipitation amounts are first increased to correspond to maximum meteorologic factors such as wind speed and maximum moisture content of the atmosphere.

(1) Estimates of PMP are based generally on the results of the analyses of observed storms. More than 600 storms throughout the United States have been analyzed in a uniform manner, and summary sheets have been distributed to government agencies and the engineering profession. These summary sheets include depth-area-duration data for each storm analyzed along with broad outlines of storm magnitudes and their seasonal and geographical variations. NWS (1977) Hydrometeorlogical Report No. 51 (HMR 51) contains generalized all-season estimates for the United States, east of the 105^{th} longitude. The PMP is distributed in space and time to develop the PMS, which is a hypothetical storm that produces the PMF for a particular drainage basin.

(2) NWS (1981) HMR No. 52 provides criteria and instructions for configuring the storm to produce the PMF. The precipitation on a basin is affected by the storm placement, storm-area size, and storm orientation. The HMR52 PMS (HEC 1984) computer program uses a procedure to produce maximum precipitation on the basin. However, several trials are suggested to ensure that the maximum storm is produced. The PMS is then input to a rainfall-runoff model to determine the flood runoff.

(3) The HMR52 User's Manual shows an example application with the HEC-1 Flood Hydrograph Package. The storm hyetographs can be written to an output file, in HEC-1 input format, or to an HEC-DSS file. HEC-1 can read the DSS file to obtain the basin precipitation.

(4) Hydrometeorlogical criteria are being updated for various areas of the country. A check should be made for the most recent criteria. Figure 13-3 in EM 1110-2-1417 shows the regional reports available in 1993. The HMR52 computer program does not apply to U.S. regions west of the 105^{th} meridian.

(5) In the determination of both the SPF and the PMF, selection of rainfall loss rates and the starting storage of upstream reservoirs should be based on appropriate assumptions for antecedent precipitation and runoff for the season of the storm. Also, PMF studies should consider the capability of upstream reservoir projects to safely handle the PMF contribution from that portion of the watershed. There could be deficiencies in an upstream project spillway that significantly affects the downstream project's performance.

e. Storm duration. Hypothetical storms to be used for any particular category of hypothetical flood computation must be based on data observed within a region. For application in the design of local flood protection projects, only peak flows and runoff volumes for short durations are usually important. Accordingly, the maximum pertinent duration of storm rainfall is only on the order of the time of travel for flows from the headwaters to the location concerned. After a reasonable maximum duration of interest is established, rainfall amounts for this duration and for all important shorter durations must be established. For standard project storm determinations, this would consist of the amounts of observed rainfall in the most severe storms within the region that correspond to area sizes equal to the drainage area above the project. In the case of hypothetical storms and floods of a specified frequency, these rainfall amounts would correspond to amounts observed to occur with the specified frequency at stations spread over an area the size of the project drainage area. Larger rates and smaller amounts of precipitation would occur for shorter durations, as compared with the longer durations of interest. Once a depth-duration curve is established that represents the desired hypothetical storm rainfall, a time pattern must be selected that is reasonably representative of observed storm sequences. The HEC-1 computer program has the capability of accepting any depth-duration relation and selecting a reasonable time sequence. It is also capable of accepting specified time sequences for hypothetical storms.

f. Snowmelt contribution. Satisfactory criteria and procedures have not yet been developed for the computation of standard project and probable maximum snowmelt floods. The problem is complicated in that deep snowpack tends to inhibit rapid rates of runoff, and consequently, probable maximum snowmelt flood potential does not necessarily correspond to maximum snowpack depth or water equivalent. Snowpack and snowmelt differ at various elevations, thus adding to the complexity of the problem.

(1) Where critical durations for project design are short, high temperatures occurring with moderate snowpack depths after some melting has occurred will probably produce the most critical runoff. Where critical durations are long, as is the more usual case in the control of snowmelt floods, prolonged periods of high temperature or warm rainfall occurring with heavy snowpack amounts will produce critical conditions.

(2) The general procedure for the computation of hypothetical snowmelt floods is to specify an initial snowpack for the season that would be critical. In the case of SPF's a maximum observed snowpack should be assumed. The temperature sequence for SPF computation would be that which produces the most critical runoff conditions and should be selected from an observed historical sequence. In the case of PMF computation, the most critical snowpack possible should be used and it should be considerably larger or more critical than the standard project snowpack. The temperature pattern should be selected from historical temperature sequences augmented to represent probable maximum temperature for the season. Where simultaneous contribution from rainfall is possible, a maximum rainfall for the season should be added during the time of maximum snowmelt. This would require some moderation of temperatures to ensure that they are consistent with precipitation conditions. EM 1110-2-1406 covers snowmelt for design floods, standard project and maximum probable snowmelt flood derivation.

(3) Snowmelt computations can be made in accordance with an energy budget computation, accounting for radiation, evaporation, conductivity, and other factors, or by a simple relation with air temperature, which reflects most of these other influences. The latter procedure is usually more satisfactory in practical situations. Snowmelt, loss rate, and unit hydrograph computations can be made by using a computer program like Flood Hydrograph Analysis, HEC-1. EM 1110-2-1417 has detailed descriptions of each computational component.